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Takii et al.

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(54) **OPHTHALMIC MEASUREMENT APPARATUS AND OPHTHALMIC MEASUREMENT PROGRAM**

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(51) **Int. Cl.**

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A61B 3/02	(2006.01)
A61B 3/107	(2006.01)
A61B 3/15	(2006.01)

(52) **U.S. Cl.**

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(58) **Field of Classification Search**

USPC 351/200–246

See application file for complete search history.

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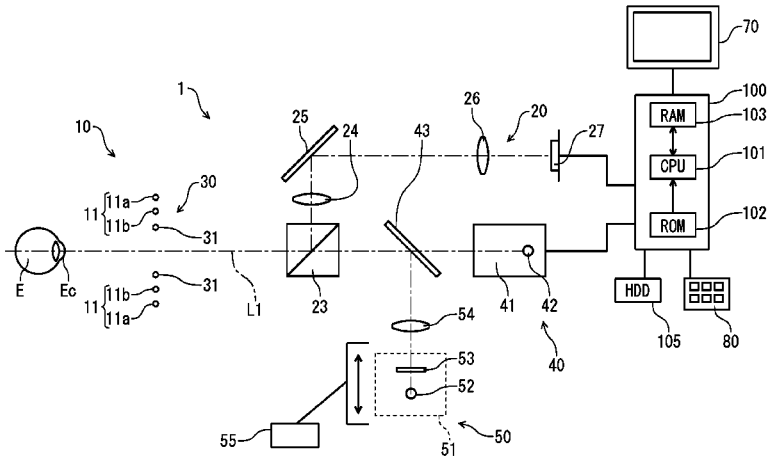
(57) **ABSTRACT**

There is provided an ophthalmic measurement apparatus **1** including: a keratoscopic projection optical system **10** that projects a pattern target toward a cornea Ec of a subject eye E; and an imaging optical system **20**, the imaging device **27** of which captures second Purkinje images Rp**1** and Rp**2** that are target images formed due to the pattern target being reflected from a posterior corneal surface of the subject eye E. In the ophthalmic apparatus **1**, a controller **100** executes a process (S**9**) of detecting the second Purkinje images Rp**1** and Rp**2** based on an imaging signal output from the imaging device **27**, and an anterior chamber information acquisition process (S**10**) of acquiring information of the posterior corneal surface of the subject eye E based on the detected result of the detecting process.

20 Claims, 6 Drawing Sheets



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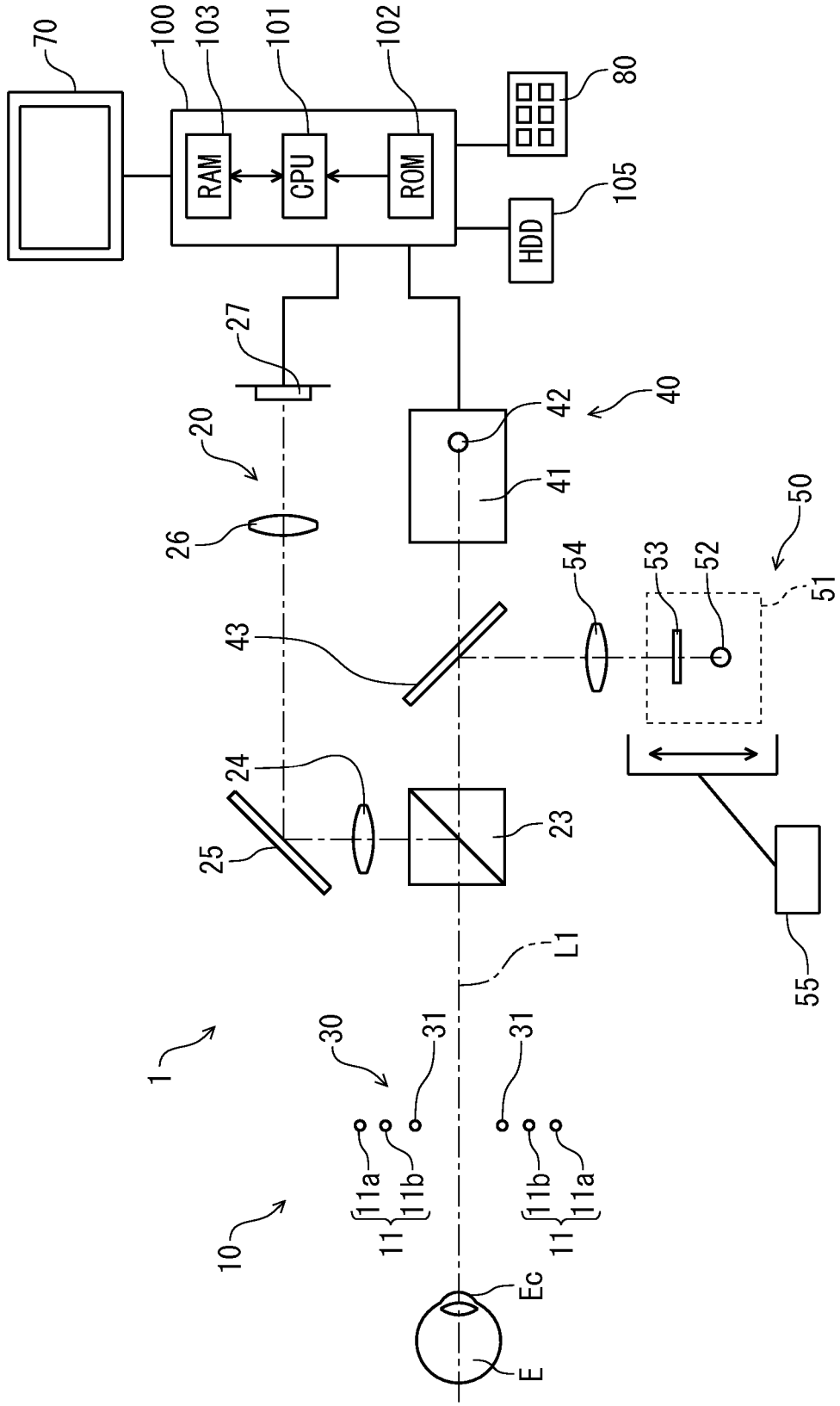

70
100
103
101
102
80
RAM
CPU
ROM
105
HDD
27
20
42
40
41
26
50
54
53
52
51
43
24
25
23
L1
55
1
30
31
31
11a
11b
11
11b
11a
11
10
Ec
E

FIG. 1

FIG. 2

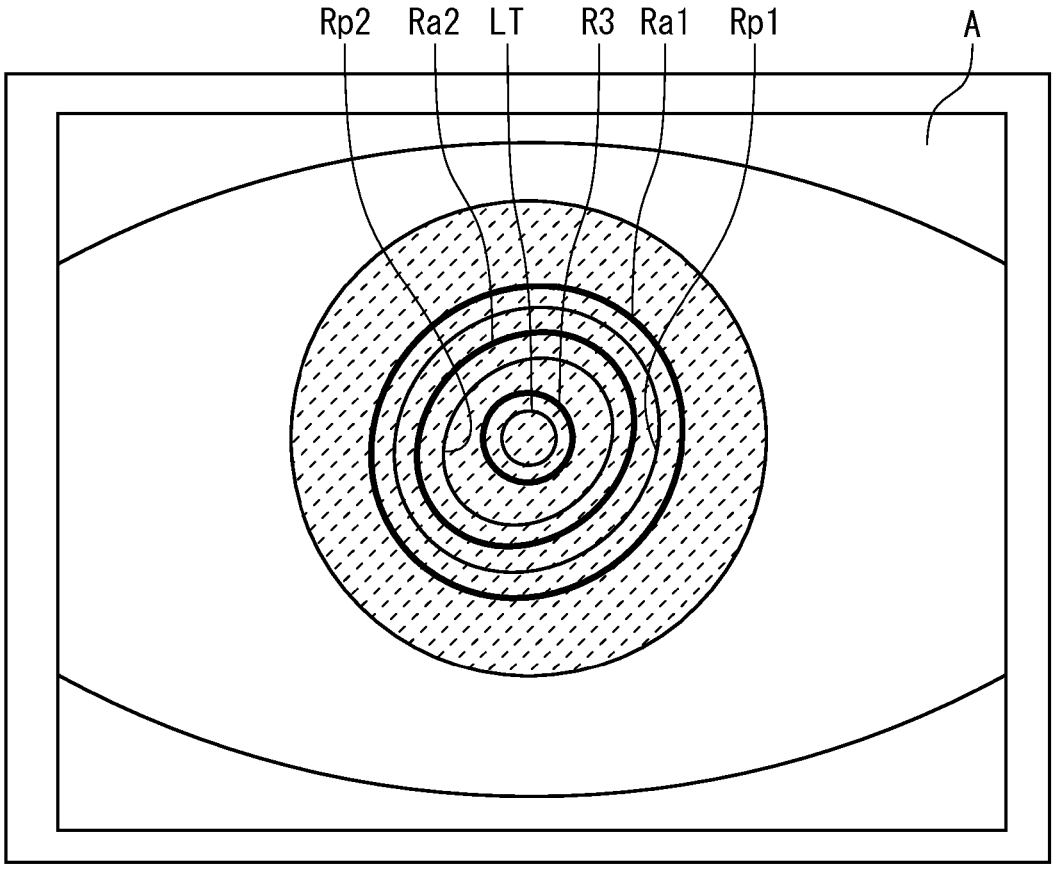


FIG. 3

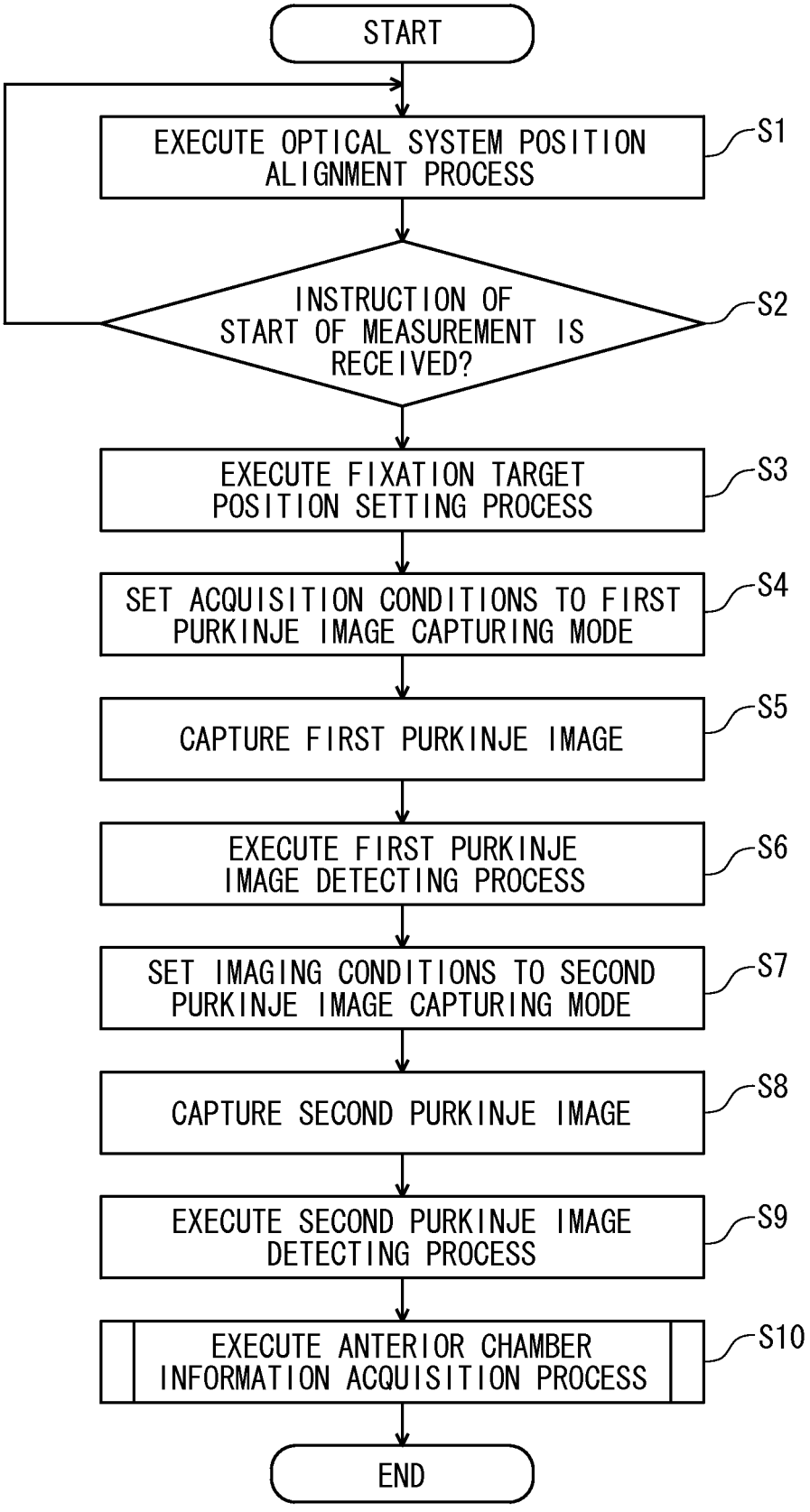

START
EXECUTE OPTICAL SYSTEM POSITION ALIGNMENT PROCESS
S1
INSTRUCTION OF START OF MEASUREMENT IS RECEIVED?
S2
EXECUTE FIXATION TARGET POSITION SETTING PROCESS
S3
SET ACQUISITION CONDITIONS TO FIRST PURKINJE IMAGE CAPTURING MODE
S4
CAPTURE FIRST PURKINJE IMAGE
S5
EXECUTE FIRST PURKINJE IMAGE DETECTING PROCESS
S6
SET IMAGING CONDITIONS TO SECOND PURKINJE IMAGE CAPTURING MODE
S7
CAPTURE SECOND PURKINJE IMAGE
S8
EXECUTE SECOND PURKINJE IMAGE DETECTING PROCESS
S9
EXECUTE ANTERIOR CHAMBER INFORMATION ACQUISITION PROCESS
S10
END

FIG. 4

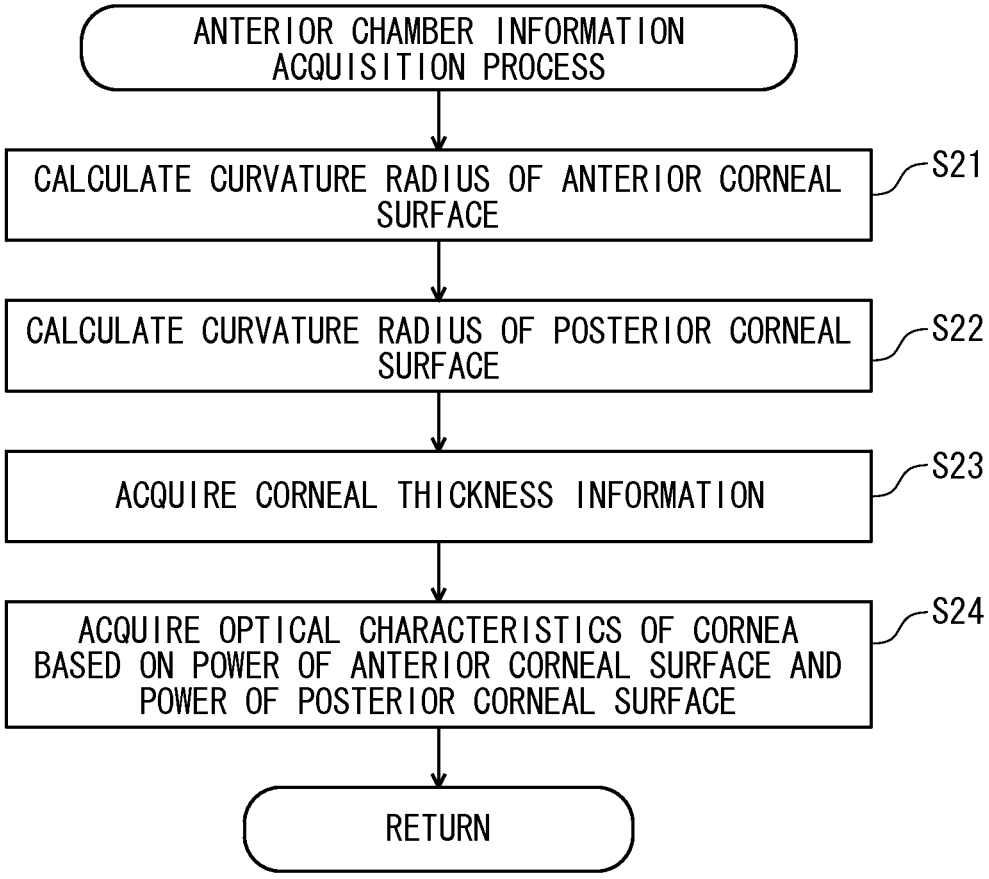

ANTERIOR CHAMBER INFORMATION ACQUISITION PROCESS
CALCULATE CURVATURE RADIUS OF ANTERIOR CORNEAL SURFACE
S21
CALCULATE CURVATURE RADIUS OF POSTERIOR CORNEAL SURFACE
S22
ACQUIRE CORNEAL THICKNESS INFORMATION
S23
ACQUIRE OPTICAL CHARACTERISTICS OF CORNEA BASED ON POWER OF ANTERIOR CORNEAL SURFACE AND POWER OF POSTERIOR CORNEAL SURFACE
S24
RETURN

FIG. 5

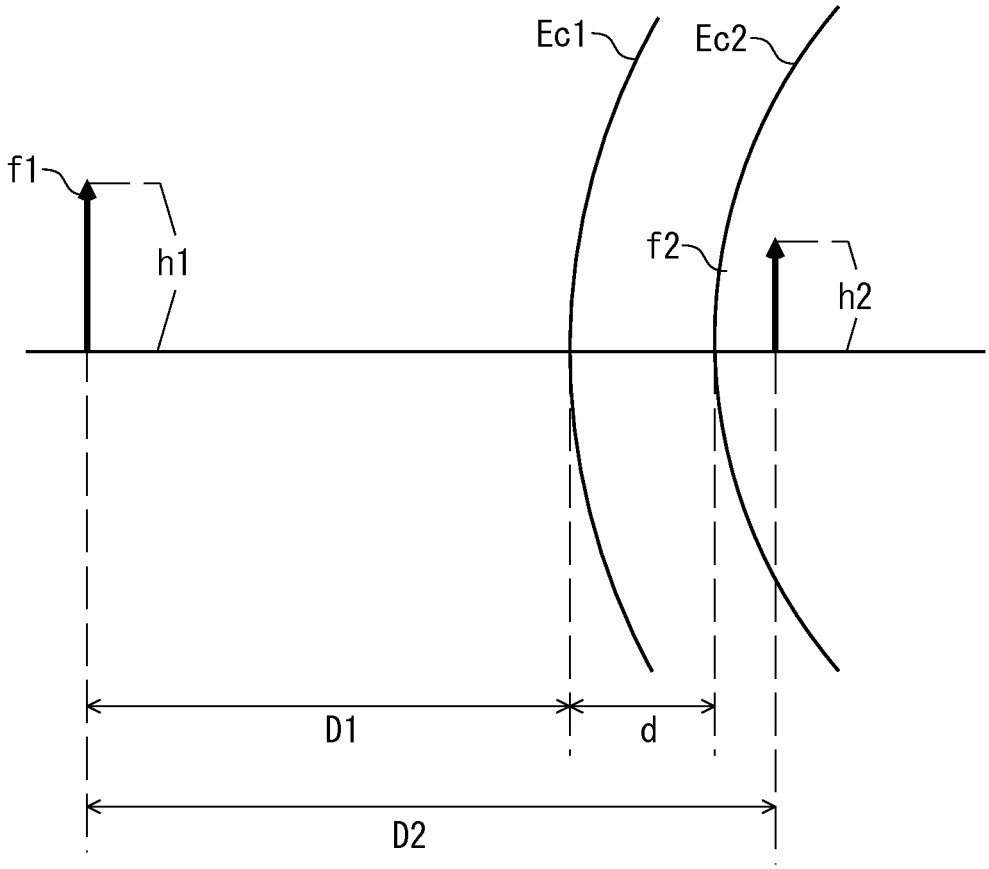
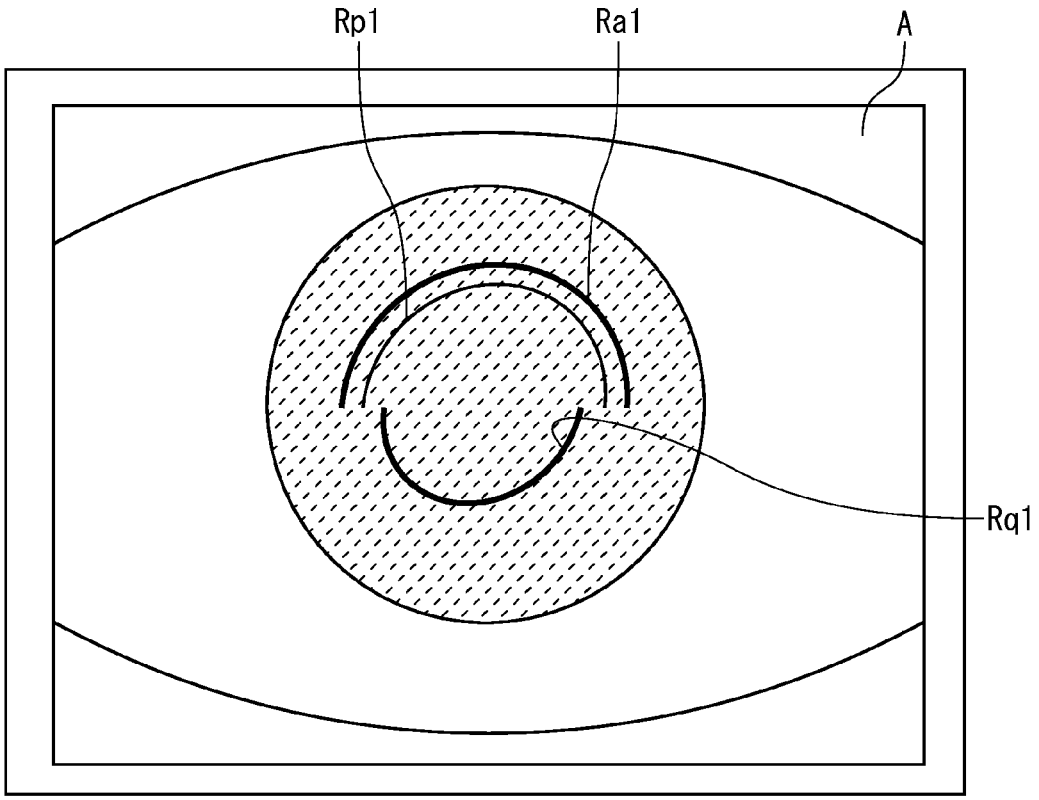


FIG. 6



OPHTHALMIC MEASUREMENT APPARATUS AND OPHTHALMIC MEASUREMENT PROGRAM

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority from Japanese Patent Application No. 2013-248476, filed on Nov. 29, 2013, the entire subject matter of which is incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates an ophthalmic measurement apparatus, which measures a subject eye, an ophthalmic measurement method and an ophthalmic measurement program.

BACKGROUND

A posterior corneal surface, for example, the curvature and shape of the posterior corneal surface may be measured as ophthalmic characteristics of a subject eye. For example, the curvature of the posterior corneal surface is used for calculating a corneal refractive power, and the calculated result is used for calculating an intraocular lens power. Conventionally, characteristics of the posterior corneal surface are acquired by analyzing a cross-sectional image of the cornea which is captured using apparatus such as a Scheimpflug camera and an anterior chamber OCT apparatus.

An example of such apparatus is disclosed in JP-A-2012-055337.

In the above-mentioned examples of the related art, a cross-sectional image of the cornea is required. Accordingly, a user is required to be prepared with an apparatus that captures a cross-sectional image of the cornea.

When the cornea is measured in a plurality of meridional directions using a Scheimpflug camera, an optical system should be turned so as to obtain a cross-sectional image at different angles, and thereby such apparatus results to have rather complicated configuration. Since an anterior chamber OCT requires an interference optical system and an optical scanner, the anterior chamber OCT apparatus is relatively expensive.

SUMMARY OF THE INVENTION

The present disclosure has been made in view of the above circumstances, and one of objects of the present disclosure is to provide an ophthalmic measurement apparatus and a method for measuring a cornea of a subject eye, which are capable of acquiring information of the posterior corneal surface of a subject eye using an apparatus with a simple configuration.

According to an illustrative embodiment of the present disclosure, there is provided an ophthalmic measurement apparatus including: a projection optical system configured to project a pattern target toward a cornea of a subject eye; an imaging optical system provided with an imaging device configured to capture an image of the subject eye, the image including a second Purkinje image, which is a target image formed due to the pattern target being reflected from a posterior corneal surface of the subject eye; a processor connected to the imaging device; and a memory storing computer readable instructions, when executed by the processor, causing the processor to function as: a detecting unit configured to detect the second Purkinje image from the image captured by the imaging device; and an acquiring unit configured to acquire posterior corneal surface information related to the posterior corneal surface of the subject eye based on the second Purkinje image detected by the detecting unit.

According to another illustrative embodiment of the present disclosure, there is provided a method for measuring cornea of a subject eye, the method including: projecting a pattern target toward a cornea of a subject eye; capturing an image of the subject eye, the image including a second Purkinje image, which is a target image formed due to the pattern target being reflected from a posterior corneal surface of the subject eye; detecting the second Purkinje image from the image of the subject eye; and acquiring posterior corneal surface information related to the posterior corneal surface of the subject eye based on the second Purkinje image detected from the image from the image of the subject eye.

According to the present disclosure, an ophthalmic measurement apparatus with a simple configuration can acquire information of a posterior corneal surface of a subject eye.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. **1** is a schematic view illustrating a configuration of an ophthalmic measurement apparatus according to an embodiment;

FIG. **2** is a schematic view of an anterior chamber image captured by the ophthalmic measurement apparatus;

FIG. **3** is a flowchart illustrating a process of a CPU relative to the measurement operation of the ophthalmic measurement apparatus;

FIG. **4** is a flowchart illustrating an anterior chamber information acquisition process;

FIG. **5** is a schematic view describing a method of calculating a curvature radius of a posterior corneal surface; and

FIG. **6** is a schematic view of an anterior chamber image according to a modification example.

DETAILED DESCRIPTION

Hereinafter, an embodiment of the present disclosure will be described with reference to the accompanying drawings. First, a schematic configuration of an ophthalmic measurement apparatus **1** according to the embodiment will be described with reference to FIG. **1**.

The ophthalmic measurement apparatus **1** illustrated in FIG. **1** measures the posterior corneal surface of a subject eye E. As illustrated in FIG. **1**, the ophthalmic measurement apparatus **1** is provided with a keratoscopic projection optical system **10**; an imaging optical system (light receiving optical system) **20**; and a controller **100**. The ophthalmic measurement apparatus **1** of the embodiment has an alignment projection optical system **30**; a second measurement optical system **40**; and a fixation target projection optical system **50**. These optical systems are built in a housing, which is not illustrated in the accompanying drawings A well-known alignment moving mechanism enables three-dimensional movement of the housing with respect to the subject eye. For example, the housing may be moved according to an instruction input from an examiner (user) through an operation console having user interface such as a joystick.

The keratoscopic projection optical system **10** projects (projects the light of) a pattern target (measurement target) on the cornea of the subject eye E. In the embodiment, the target from the keratoscopic projection optical system **10** is used to measure the posterior surface (back surface) of the cornea. For example, the shape, the curvature radius, and the refractive power of the posterior corneal surface and the like may be measured. For example, a corneal thickness, and an astigmatic axis angle for the posterior corneal surface may also be measured. As will be described later, the pattern target may be used to measure the anterior surface (front surface) of the cornea (for example, used to measure the shape, the curvature radius, the refractive power of the anterior corneal surface, a corneal thickness, and an astigmatic axis angle).

The keratoscopic projection optical system **10** has a light source **11**. For example, the projection optical system **10** may project a ring-shaped target on the cornea of the eye E. In the embodiment, the light source **11** includes a first ring light source **11***a* and a second ring light source **11***b*. For example, a ring-shaped light source may be used as the first ring light source **11***a* and the second ring light source **11***b*, or each of the first ring light source **11***a* and the second ring light source **11***b* may adopt a configuration obtained by combining together a plurality of LEDs arranged so as to form a ring shape and a ring-shaped pattern opening disposed in front of the LEDs. Each of the ring light sources **11***a* and **11***b* is formed into a ring shape which has a measurement optical axis L**1** as the center thereof. In the embodiment, two ring light sources **11***a* and **11***b* project two ring-shaped targets of different sizes, respectively.

As illustrated in FIG. **2**, the anterior corneal surface reflects (and scatters) the light flux of the target projected from the first ring light source **11***a*, and a first ring-shaped Purkinje image Ra**1** can be formed by the reflected light. The posterior corneal surface reflects (and scatters) the light of the target projected from the first ring light source **11***a*, and a second ring-shaped Purkinje image Rp**1** can be formed by the reflected light. Typically, the luminance of the second Purkinje image is lower than that of the first Purkinje image. In the embodiment, the second Purkinje image Rp**1** is formed inward of the first Purkinje image Ra**1** due to the curve of a cornea Ec. Similarly, the anterior corneal surface reflects the light flux from the second ring light source **11***b*, and a first Purkinje image Ra**2** can be formed by the reflected light. The posterior corneal surface reflects the light flux from the second ring light source **11***b*, and a second Purkinje image Rp**2** can be formed by the reflected light.

In the embodiment, the first ring light source **11***a* has a diameter greater than that of the second ring light source **11***b*. The second Purkinje image Rp**1** occurs on an outer circumference of the second Purkinje image Rp**2**. In the embodiment, the second Purkinje images Rp**1** and Rp**2** are mainly used to measure the cornea, which will be described later in detail.

In the embodiment, the position of the projection of the pattern target is displaced by alternately turning on the light sources. The two ring light sources **11***a* and **11***b* may be concurrently turned on. When the two ring light sources are concurrently turned on, the projection positions preferably do not overlap with each other. Only one of the two ring light sources **11***a* and **11***b* may be turned on. For example, the light source **11** may emit infrared light or visible light.

The shape and position of the light source **11** are not limited to the configuration in which the light source **11** is formed by the two ring light sources **11***a* and **11***b*. For example, the light source **11** may be a single ring light source. Moreover, the light source **11** may be three or more ring light sources. The light source **11** may be a plurality of point light sources. At this time, the light source **11** preferably includes at least three or more point light sources among the point light sources, which are disposed on the same circumference. The light source **11** may be an intermittent ring light source. That is, the examples of the pattern target include a pattern that is formed by three or more point targets which are concentrically disposed, a dot matrix target formed by point targets arranged in grid, an intermittent ring pattern, and the like, in addition to the ring-shaped target pattern of the embodiment.

The alignment projection optical system **30** projects an alignment target on the cornea of the subject eye E. The alignment projection optical system **30** has a light source **31**. In the embodiment, the light source **31** is disposed inward of the light source **11** of the keratoscopic projection optical system **10**. The light source **31** has a projection light source **31** (for example, λ=970 nm) that emits infrared light, and is used to project an alignment target on the cornea of the subject eye. An alignment target projected on the cornea is used for a position alignment (for example, automatic alignment, alignment detection, or a manual alignment) with respect to the subject eye. As illustrated in FIG. **2**, in the embodiment, the alignment projection optical system **30** projects a ring target R**3** as an alignment target. The ring target image R**3** may be also used as a Mayer ring. The light source **31** of the alignment projection optical system **30** is also used as anterior chamber illumination optical system that project illumination light on the cornea of the subject eye E, which diagonally illuminates the anterior chamber. The projection optical system **30** may be further provided with an optical system so as to project parallel light on the cornea, and a forward and rearward alignment may be performed by the combination of the parallel light and finite light through the alignment projection optical system **30**.

In the embodiment, the imaging optical system **20** includes a two-dimensional imaging device **27**, and can capture an image of the front surface of the anterior chamber of the subject eye from a forward direction. More specifically, the imaging optical system **20** is provided with a dichroic mirror **23**; an objective lens **24**; a mirror **25**; an imaging lens **26**; and the two-dimensional imaging device **27**. For example, the two-dimensional imaging device **27** may be disposed at a position conjugate with the anterior chamber of the subject eye. The imaging optical system **20** is disposed in such a manner that an optical axis of the imaging optical system **20** is coaxial with that of the fixation target projection optical system **50**.

The dichroic mirror **23** (beam splitter) is an optical path splitting member that splits an optical path of the imaging optical system **20** from an optical path of the second measurement optical system **40** (the details will be described later).

Here, light from the keratoscopic projection optical system **10** and the alignment projection optical system **30** is reflected from the anterior chamber, and the reflected light is formed as an image (photodetected) on the imaging device (for example, two-dimensional imaging device) **27** via the optical path of the imaging optical system **20**. Accordingly, the imaging optical system **20** captures an image of the anterior chamber that the keratoscopic projection optical system **10** irradiates with light, and thus the imaging optical system **20** can capture an anterior chamber image A that contains the target images (for example, the first Purkinje images Ra**1** and Ra**2**, and the second Purkinje images Rp**1** and Rp**2**) formed on the cornea Ec. The imaging optical

system **20** captures an image of the anterior chamber that the alignment projection optical system **30** irradiates with light, and thus the imaging optical system **20** can capture the anterior chamber image A that contains the ring target image R**3** formed on the cornea Ec.

The second measurement optical system **40** is arranged at a position on an optical path that transmits through the dichroic mirror **23** in the imaging optical system **20**.

The second measurement optical system **40** is provided with a second measurement optical unit **41** and a dichroic mirror **43**. The second measurement optical system **40** shares the dichroic mirror **23** with the imaging optical system **20**. The second measurement unit **41** is configured to project second measurement light on the subject eye, and photodetects the reflected light. The second measurement unit **41** has a light source **42** that emits the second measurement light.

For example, the second measurement optical system **40** may be an eye axial-length measurement optical system (for example, the wavelength λ of the light source **42** is equal to 830 nm) that measures the axial length of the eye by detecting interference light resulting from measurement light and reference light, an eye refractive power measurement optical system (for example, the wavelength λ of the light source **42** is 870 nm) that measures an eye refractive power by detecting reflected light projected on the fundus of the subject eye, and the like.

The fixation target projection optical system **50** is arranged at a position on an optical path that is reflected by the dichroic mirror **43** in the second measurement optical system **40**.

The fixation target projection optical system **50** is used to fix the vision of the subject eye E during a measurement. In the embodiment, the fixation target projection optical system **50** has a fixation target unit **51**; a lens **54**; and a fixation target position adjusting mechanism **55**.

The fixation target unit **51** has a light source **52** and a target board **53**. When light is emitted from the light source **52**, a fixation target formed on the target board **53** is projected on the subject eye E via the lens **54** and the like. The fixation target position adjusting mechanism **55** enables to displace the fixation target unit **51** along an optical axis L**4** of the fixation target projection optical system **50**. Accordingly, the presentation position (presentation distance) of the fixation target with respect to the subject eye E is adjusted.

Subsequently, a control system will be described. In the ophthalmic measurement apparatus **1** of the embodiment, the controller **100** serves to perform overall control of the ophthalmic measurement apparatus **1** and to calculate a measurement result.

In the embodiment, the controller **100** is connected to the light source **11**; the imaging device **27**; the light source **31**; the second measurement optical unit **41**; the light source **52**; the fixation target position adjusting mechanism **55**; a monitor **70**; a user interface **80**; and a storage device **105**.

The controller **100** is provided with a CPU **101**; a ROM **102**; and a RAM **103**. The CPU **101** is a processing device (processor) for executing various processes of the ophthalmic measurement apparatus **1**. The ROM **102** is a non-volatile storage device that stores a control program, fixed data, and the like. The RAM **103** is a rewritable volatile storage device. For example, the RAM **103** stores temporary data that the ophthalmic measurement apparatus **1** uses so as to capture an image of and measure the subject eye E.

The storage device **105** is a rewritable non-volatile storage device. In the embodiment, the storage device **105** stores at least a program for causing the controller **100** to execute an anterior chamber measurement process. The storage device **105** may store anterior chamber images captured by the ophthalmic measurement apparatus **1**.

Here, a photodetection signal (imaging signal) output from the imaging device **27** is processed by the controller **100**, and is displayed on the monitor **70**. The controller **100** detects an alignment state of the subject eye E based on the photodetection signal output from the imaging device **27**.

In this embodiment, the CPU **101** serves as a processor connected to the imaging device **27**, and the ROM **102** and RAM **103** serves as a memory storing computer readable instructions, when executed by the processor, causing the processor to function as: a detecting unit configured to detect the second Purkinje images Rp**1**, Rp**2** from the image captured by the imaging device **27**; and an acquiring unit configured to acquire posterior corneal surface information related to the posterior corneal surface of the subject eye E based on the second Purkinje images Rp**1**, Rp**2** detected by the detecting unit.

In the embodiment, the CPU **101** also functions a mode setting unit, an imaging control unit, a fixation target position control unit, and a projection control unit.

The mode setting unit may be configured to set an operational mode into one of: a first Purkinje image capturing mode in which the imaging optical system is set to capture the image of the subject eye for detecting the first Purkinje image; and a second Purkinje image capturing mode in which the imaging optical system is set to capture the image of the subject eye for detecting the second Purkinje image.

The imaging control unit may be configured to change imaging condition of the image captured by the imaging device in the imaging optical system in accordance with the operational mode being set by the mode setting unit.

The fixation target position control unit may be configured to control the fixation target position adjusting mechanism to set the position of the fixation target to be at a far point of the subject eye when the imaging device captures the image for detecting the second Purkinje image at least when the operational mode is set to the second Purkinje image capturing mode.

The projection control unit may be configured to control the projection optical system to selectively project at least one of the plurality of ring target patterns.

The operation of the ophthalmic measurement apparatus **1** having the above-mentioned configuration will be described.

In the embodiment, an example of the operation of the apparatus relative to the measurement of the anterior chamber is illustrated with reference to a flowchart in FIG. **3**. First, the CPU **101** performs an optical system position alignment process (S**1**). During the position alignment, the CPU **101** turns on the light source **31** of the alignment projection optical system **30**, and displays a live image (observed image) of the subject eye E on the monitor **70** based on a photodetection signal that is output from the imaging device **27** in association with the turn-on of the light source **31**. The CPU **101** electronically displays a reticle LT (refer to FIG. **2**) on the monitor **70**.

The CPU **101** detects the ring target R**3** induced by the light source **31**, based on an imaging signal from the imaging device **27**. The CPU **101** controls to activate an actuator unit (not illustrated) which moves the optical systems of the ophthalmic measurement apparatus **1** in such a manner that the ring target R**3** is disposed concentrically with the reticle LT, based on a detected result. The CPU **101** aligns the optical systems of the apparatus in a forward and

rearward direction in such a manner that a distance between the apparatus and the corneal apex becomes a predetermined operational distance, based on an imaging signal from the imaging device **27**.

The alignment may not necessarily be automatically performed. For example, the alignment may be performed based on an instruction input from the examiner. At this time, for example, the CPU **101** may receive the instruction input from the examiner through the user interface **80**, which is provided with, for example, joystick, and may move the optical systems of the ophthalmic measurement apparatus **1** based on the instruction input.

The examiner can align the respective positions of the optical systems with each other before inputting an instruction of the start of a measurement via the user interface **80** (S**2**: No). The CPU **101** executes processes after step S**3** based on the instruction of the start of a measurement from the examiner (S**2**: Yes).

In the embodiment, the presentation position (presentation distance) of the fixation target with respect to the subject eye E is set prior to measuring the anterior chamber (S**3**). At this time, the fixation target comes close to a far point of the subject eye E. For example, in the embodiment, the CPU **101** controls the fixation target position adjusting mechanism **55** based on position information of the far point of the subject eye, and disposes the fixation target at the far point of the subject eye E. As a result, the fixation prevents the subject eye from being adjusted. Accordingly, the anterior chamber is measured in a state where the pupil is less contracted. For example, the CPU **101** acquires the position information of the far point as follows. For example, if the second measurement unit **40** is configured to measure the position of the far point of the subject eye E (for example, to measure an eye refractive power), the ophthalmic measurement apparatus **1** may acquire the position information of the far point based on the measurement result of the second measurement unit **40**. A measured result of the position of the far point of the subject eye E obtained by another inspection instrument may be transmitted to the ophthalmic measurement apparatus **1**, or the examiner may directly input the position of the far point via the user interface **80**, and thereby the ophthalmic measurement apparatus **1** may acquire the position information of the far point.

Subsequently, in the embodiment, the CPU **101** sets conditions (for example, states of the optical systems), under which the ophthalmic measurement apparatus **1** acquires a target pattern image, to a first Purkinje image capturing mode (first mode) (S**4**). In this mode, an apparatus main body (for example, the controller **100**) acquires data used in a process of detecting the first Purkinje images Ra**1** and Ra**2** (for example, process of detecting the position and shape of the first Purkinje images). In the embodiment, for example, in the first Purkinje image capturing mode, an anterior chamber image containing the first Purkinje images Ra**1** and Ra**2** is captured (taken), which will be described later. In the process in step S**4**, the amount of light of the light flux output from the light source **11**, a gain of the imaging device **27**, and the like are preferably adjusted in such a manner that a clean anterior chamber image containing the first Purkinje images Ra**1** and Ra**2** is captured. In the process in step S**4**, light photodetected by the imaging device **27** may be limited by the replacement and disposition of a filter for adjusting the amount of light on the optical path of each of the keratoscopic projection optical system **10** and the imaging optical system **20**.

Subsequently, the CPU **101** captures an anterior chamber image used in the process of detecting the first Purkinje images Ra**1** and Ra**2** (S**5**). In the process in step S**5**, the CPU **101** may selectively project at least one of a plurality of the ring target patterns. More specifically, the first Purkinje image Ra**1** based on the light flux from the first ring light source **11***a* and the first Purkinje image Ra**2** based on the light flux from the second ring light source **11***b* may be captured so as to be respectively contained in separate images by turning on the first ring light source **11***a* and the second ring light source **11***b* in turn, one at a time. The first Purkinje images Ra**1** and Ra**2** may be captured so as to be contained in a single image by concurrently turning on the two ring light sources **11***a* and **11***b*. When a plurality of the first Purkinje images are captured in a single image, the first Purkinje images preferably do not overlap with each other.

After the process in step S**5**, the CPU **101** executes a first Purkinje image detecting process (S**6**). In the embodiment, in the first Purkinje image detecting process (S**6**) and a second Purkinje image detecting process (S**9**), the first Purkinje images Ra**1** and Ra**2** are detected based on an imaging signal output from the imaging device **27**. More specifically, the first Purkinje images Ra**1** and Ra**2** are detected using the image captured in the process in step S**5**. In the embodiment, target position information of each of the first Purkinje images Ra**1** and Ra**2** is acquired as a result (detected result) of the process in step S**6**. For example, the target position information may be two-dimensional position information of each of the first Purkinje images Ra**1** and Ra**2**.

Various processes can be executed in step S**6**. For example, the first Purkinje images may be detected based on luminance information of the anterior chamber image. As illustrated in FIG. **2**, each of the first Purkinje images Ra**1** and Ra**2** has a width in the meridional direction. For example, the position of each of the first Purkinje images Ra**1** and Ra**2** may be detected from a region which contains continuous luminance values greater than or equal to a predetermined threshold value in the meridional distribution of luminance of the image of the cornea. At this time, more specifically, the position of a peak value (maximum value) or the position of a median value of the distribution in the region, which contains the continuous luminance values greater than or equal to a predetermined threshold value, may be detected as the position of each of the first Purkinje images Ra**1** and Ra**2**. For example, the CPU **101** makes the RAM **102**, the storage device **105**, and the like store the detected result. The detected result of the first Purkinje images Ra**1** and Ra**2** is not limited to the target position information, and for example, the detected result may be information of the anterior corneal surface. For example, the information of the anterior corneal surface may be the curvature radius, the three-dimensional shape, or the power of the anterior corneal surface.

Subsequently, in the embodiment, the CPU **101** sets conditions (or acquisition conditions, and for example, states of the optical systems), under which the ophthalmic measurement apparatus **1** captures a target pattern image, to a second Purkinje image capturing mode (second mode) (S**7**). In this mode, the ophthalmic measurement apparatus **1** acquires data used in a process of detecting the second Purkinje images Rp**1** and Rp**2** (for example, process of detecting the position and shape of the second Purkinje images). In the embodiment, for example, in the second Purkinje image capturing mode, an anterior chamber image containing the second Purkinje images Rp**1** and Rp**2** is captured (taken). In the process in step S**7**, the amount of light of the light flux output from the light source **11**, a gain of the imaging device **27**, and the like are preferably

adjusted in such a manner that a clean image containing the second Purkinje images Rp**1** and Rp**2** is captured. For example, the CPU **101** may increase the value of at least one of the amount of light from the light source **11** and the gain of the imaging device **27** in the first Purkinje image capturing mode.

In the process in step S**7**, the optical systems (for example, the alignment projection optical system **30** and the second measurement optical system **40**) other than the keratoscopic projection optical system **10** are preferably prevented from irradiating light on the subject eye E, which will be described later in detail. For example, the CPU **101** may reduce the amount of light for projecting a fixation target output from the light source **52** so as to reduce the contraction of the pupil resulting from glare. At this time, the anterior chamber illumination (for example, the light source **31**) may be turned off. That is, the second Purkinje images are preferably captured, and it may not be possible to confirm each portion of the anterior chamber on the image.

For example, the reflection of light from the fundus preferably prevents transillumination (light applied to the cornea from the fundus side). For example, the amount of light from each of the light source **31**, the light source **42**, and the like may be reduced. As a result, it is easy to capture the second Purkinje images Rp**1** and Rp**2** due to differences between background and the images.

Subsequently, the CPU **101** captures an anterior chamber image used in the process of detecting the second Purkinje images Rp**1** and Rp**2** (S**8**). In the process in step S**8**, the CPU **101** may selectively project at least one of a plurality of the ring target patterns. More specifically, the second Purkinje image Rp**1** based on the light flux from the first ring light source **11***a* and the second Purkinje image Rp**2** based on the light flux from the second ring light source **11***b* may be captured so as to be respectively contained in separate images by turning on the two ring light sources **11***a* and **11***b* in turn. At this time, one of the second Purkinje images Rp**1** and Rp**2** can be prevented from overlapping with a reflected image formed by the light flux from other light sources. Accordingly, in a subsequent second Purkinje image detecting process (S**9**), good detection of the second Purkinje images Rp**1** and Rp**2** is easy.

The second Purkinje images Rp**1** and Rp**2** may be captured so as to be contained in a single image by concurrently turning on the two ring light sources **11***a* and **11***b*. The image contains not only the second Purkinje images but also other reflected images (the first Purkinje images Ra**1** and Ra**2**, and the like) of the target light flux. For this reason, when a plurality of the second Purkinje images are captured in a single image, the second Purkinje images preferably do not overlap with the other reflected images.

After the process in step S**8**, the CPU **101** executes the second Purkinje image detecting process (S**9**). In the embodiment, in the second Purkinje image detecting process (S**9**), the second Purkinje images are detected based on an imaging signal output from the imaging device **27**. More specifically, the second Purkinje images are detected using the image captured in the process in step S**8**. In the embodiment, position and shape information (for example, coordinate data for the location of each of the images) of each of the second Purkinje images Rp**1** and Rp**2** is acquired as a result (detected result) of the process in step S**9**. For example, more specifically, a detected result is acquired by storing the detected result in the RAM **102**.

Various processes can be executed in step S**9**. For example, also in the process in step S**9** similar to the process in step S**6**, the second Purkinje images may be detected based on the luminance information of the anterior chamber image. Each of the second Purkinje images Rp**1** and Rp**2** has a width in the meridional direction. For example, the position of each of the second Purkinje images Rp**1** and Rp**2** may be detected from a region which contains continuous luminance values greater than or equal to a predetermined threshold value in the meridional distribution of luminance of the image of the cornea. The image acquired in the process in step S**8** contains at least the first Purkinje images. Typically, the first Purkinje image is bright and distinct compared to the second Purkinje image. For example, the second Purkinje images Rp**1** and Rp**2** may be detected from a region containing a low peak luminance, with respect to a region that contains the first Purkinje image Ra**1** and Ra**2** in the meridional distribution of luminance. Typically, since the second Purkinje images are formed inward of (close to the optical axis) the first Purkinje images, the second Purkinje images Rp**1** and Rp**2** may be detected from a region that contains a peak occurring close to the optical axis L**1**, with respect to the region that contains the first Purkinje images Ra**1** and Ra**2** in the meridional distribution of luminance. Since each of the second Purkinje images Rp**1** and Rp**2** has a width in the meridional direction, the detailed position of each of the second Purkinje images Rp**1** and Rp**2** may be detected based on a distribution shape. For example, the position of a peak value (maximum value) or the position of a median value of the distribution may be detected as the position of each of the second Purkinje images Rp**1** and Rp**2**.

Subsequently, the CPU **101** executes an anterior chamber information acquisition process (S**10**). In the anterior chamber information acquisition process (S**10**) of the embodiment, at least information of the posterior corneal surface is acquired as anterior chamber information based on the detected result of the second Purkinje images Rp**1** and Rp**2**.

Here, an example of the anterior chamber information acquisition process will be described with reference to FIG. **4**. In the anterior chamber information acquisition process (S**10**) of the embodiment, first, the CPU **101** calculates a curvature radius r**1** of an anterior corneal surface Ec**1** (S**21**). For example, it is possible to obtain the curvature radius r**1** of the anterior corneal surface Ec**1** based on the first Purkinje images Ra**1** and Ra**2** detected in the process in step S**6**. Specifically, there is a technique of obtaining the corneal curvature radius r**1** based on the image height (for example, distance between the position (for example, the center of an image) of the optical axis L**1** on the image and the first Purkinje images Ra**1** and Ra**2** under the assumption that the optical axis L**1** passes through the center of the cornea) of each of the first Purkinje images Ra**1** and Ra**2**. For example, with regard to details of this technique, refer to JP-A-2003-111727 filed by the present applicant.

In the embodiment, since each of the first Purkinje images Ra**1** and Ra**2** has a ring shape, it is possible to obtain the curvature radius r**1** of a cornea Ec in an arbitrary meridional direction thereof. For this reason, as illustrated in the embodiment, it is possible to obtain the curvature radiuses r**1** in a plurality of meridional directions.

In the embodiment, since the plurality of first Purkinje images Ra**1** and Ra**2** having different diameters are detected, it is possible to obtain a curvature radius from the detected result of the first Purkinje images Ra**1** and Ra**2**.

Subsequently, the CPU **101** calculates a curvature radius r**2** of a posterior corneal surface Ec**2**. For example, it is possible to obtain the curvature radius r**2** of the posterior corneal surface Ec**2** from the detected result of the second Purkinje images Rp**1** and Rp**2** obtained in the process in step

S9, and from the curvature radius r1 of the anterior corneal surface Ec1 obtained in the process in step S21.

Here, an example of a method of obtaining the curvature radius r2 of the posterior corneal surface Ec2 will be described with reference to FIG. 5. Here, the paraxial approximation is illustrated for descriptive purposes. In FIG. 5, a posterior-surface reflected image f2 of an object f1 is formed on the posterior corneal surface Ec2 under the assumption that the optical axis L1 passes through the center of the cornea. In FIG. 5, the tip of an arrow indicative of the object f1 indicates the position of the light source 11 (the first ring light source 11*a* or the second ring light source 11*b*). Accordingly, an object height h1 indicates a distance from the optical axis L1 to the light source 11. In contrast, the tip of an arrow indicative of the posterior-surface reflected image f2 indicates the position of a ring image that is formed by the light source 11 positioned at the tip of the arrow indicative of the object height h1. That is, an image height h2 of the posterior-surface reflected image f2 indicates a distance from the optical axis L1 to the ring image formed on the posterior corneal surface Ec2.

In FIG. 5, D1 indicates a distance from the object f1 to the anterior corneal surface Ec1. D2 indicates a distance from the object f1 to the posterior-surface reflected image f2. d is a corneal thickness (an example of corneal thickness information) at the reference position of the cornea. Here, d is the corneal thickness of a center corneal portion, and indicates a corneal thickness at a position through which the optical axis L1 passes. In the embodiment, the distance D1 is set to a fixed value obtained as a result of the optical system position alignment process (S1). For example, the corneal thickness d may be a value obtained by well-known pachymetry such as an ultrasound measurement method. A corneal pachymetry optical system may be provided in the secondary measurement optical system 40, and a measured result thereof may be used as the corneal thickness d.

Here, for example, it is possible to express the image height h2 using Expression (1) shown below. Hereinafter, the image height h2 indicates an image height when the object height h1 is equal to 1.

$$h2=\beta\times\left[\left(1-\frac{d}{n}\times\frac{n-1}{r1}\right)-D2\times\left\{-\left(\frac{n-1}{r1}+\left(\frac{d}{n}\times\frac{n-1}{r1}\right)\times\left(\frac{-2n}{r2}\right)\right)\right\}\right] \quad (1)$$

The value n indicates a corneal refractive index. The value β is a correction coefficient for a magnification (or magnitude) of an image. More specifically, β corrects the influence of refraction by the cornea. For example, it is possible to express D2 and β using Expressions (2) and (3) below.

$$D2=\frac{-D1-\frac{d}{n}\left(1-D1\times\frac{n-1}{r1}\right)}{-\left[1-D1\times\frac{n-1}{r1}+\left\{-D1-\frac{d}{n}\left(1-D1\times\frac{n-1}{r1}\right)\right\}\times\frac{-2n}{r2}\right]} \quad (2)$$

$$\beta=\frac{n}{nD2+d}\times\left(\frac{\frac{nD2+d}{n}}{-1+\frac{nD2+d}{n}\times\frac{1-n}{r1}}\right) \quad (3)$$

For example, a measured value based on the result obtained in the second Purkinje image detecting process (S9) is used as the image height h2. For this reason, it is possible to obtain the value of the curvature radius r2 of the posterior corneal surface Ec2 from Expression (1).

Here, the paraxial approximation is illustrated, but corrections or modifications can also be made to the above-mentioned expressions depending on an actual design of the apparatus.

In the process in step S22, the curvature radius r2 of the posterior corneal surface may be obtained by methods other than the calculation made by the CPU 101. For example, the CPU 101 may obtain the curvature radius r2 of the posterior corneal surface Ec2, using a table in which corneal parameters (for example, corneal thickness information and anterior surface curvature information) and the curvature radius r1 of the posterior corneal surface Ec2 are associated with each other. In one of the methods, a table is pre-stored in a storage device such as the storage device 105, and the table stores the curvature radius r2 of the posterior corneal surface Ec2 in association with the value of each of the curvature radiuses r1 of the anterior corneal surface Ec1 and a reference corneal thickness d. For example, the curvature radius r2 in the table may be a value obtained by the above-mentioned expressions. At this time, the CPU 101 refers to the table, and acquires a value from the table as the curvature radius r2 of the posterior corneal surface Ec2, in which the value from the table corresponds to the curvature radius r1 of the anterior corneal surface Ec1 obtained in the process in step S21 and the reference corneal thickness d.

The curvature and the curvature radius of the posterior corneal surface may be obtained each for different meridional directions, or may be obtained by averaging multiple curvature and curvature radius obtained each for different meridional directions.

Sequential description will be made with reference to the flowchart illustrated in FIG. 4. Subsequently, the CPU 101 acquires corneal thickness information (S23). For example, information indicative of a thickness distribution of the cornea in a specific meridional direction may be acquired as the corneal thickness information. For example, it is possible to obtain a thickness distribution of the cornea in a single meridional direction from values for the curvature radius r1 of the anterior corneal surface Ec1, the curvature radius r2 of the posterior corneal surface Ec2, and the reference corneal thickness d in the single meridional direction. In the process in step S23, information indicative of a thickness distribution of the entirety of the cornea may be acquired based on a thickness distribution of the entirety of the cornea in the plurality of meridional directions.

Subsequently, in the embodiment, the CPU 101 obtains a corneal refractive power based on the respective curves of the anterior corneal surface and the posterior corneal surface (S24). For example, the corneal refractive power is expressed as the power (P(θ)) of the cornea Ec, or in a form of {spherical power (S), cylindrical surface power (C), astigmatic axis angle (A)}. In the embodiment, a value is acquired by combining information (for example, power and/or the value of each of S, C, and A) of the power of the anterior corneal surface Ec1 and information (for example, power and/or the value of each of S, C, and A) of the power of the posterior corneal surface Ec2. In the embodiment, a combined value is obtained which is obtained by a power vector method. Typically, it is possible to express the power P(θ) using Expression (4) below.

$$P(\theta)=S+C[\sin^2(\theta-A)] \quad (4)$$

For example, it is possible to obtain the value of each of S, C, and A from the values of corneal curvatures in the steepest meridional direction and the flattest meridional direction when a ring image formed on the cornea is subject to elliptic approximation, and from axial angles on the

steepest meridian and the flattest meridian. Accordingly, it is possible to obtain a power P**2** of the posterior corneal surface Ec**2** and the like based on the detected result of the second Purkinje images Rp**1** and Rp**2** formed on the posterior corneal surface Ec**2**. In addition, it is possible to obtain a power P**1** of the anterior corneal surface Ec**1** and the like based on the detected result of the first Purkinje images Ra**1** and Ra**2** formed on the anterior corneal surface Ec**1**.

The power P(θ) can be converted as follows.

$$P(\theta) = J_{45}\sin 2\theta + J_{180}\cos 2\theta + M \tag{5}$$

$$\text{wherein} \begin{cases} J_{45} = -\dfrac{C}{2}\sin 2A \\ J_{180} = -\dfrac{C}{2}\cos 2A \\ M = S + \dfrac{C}{2} \end{cases}$$

Here, the values of J_{45}, J_{180}, and M calculated for the power P**1** are indicated by J_{145}, J_{1180}, and M1, respectively, and the values of J_{45}, J_{180}, and M calculated for the power P**2** are indicated by J_{245}, J_{2180}, and M2, respectively. It is possible to express the values of J_{45}, J_{180}, and M for a combined power value Pmix(θ) by the following expression (6).

$$\begin{cases} J_{45} = J1_{45} + J2_{45} \\ J_{180} = J1_{180} + J2_{180} \\ M = M1 + M2 \end{cases} \tag{6}$$

A combined value of the values of the power (refractive power value), the spherical power (S), the cylindrical surface power (C), and the astigmatic axis angle (A) is obtained by putting a result from Expression (6) into Expression (5). The calculation of a combined value is not limited to the above-mentioned method. For example, a combined value of a ray trace power and the like may be obtained.

In the embodiment, the execution of the process in step S**24** ends the cornea information acquisition process. As a result, the process of the flowchart illustrated in FIG. **3** ends.

As described above, in the embodiment, the CPU **101** acquires the information of the posterior corneal surface Ec**2** (the curvature radius r**2** of the posterior corneal surface Ec**2**, the corneal thickness distribution information, the power of the cornea Ec, and the like) based on the result of the process (S**9**) of detecting the second Purkinje images formed on the posterior corneal surface Ec**2**. Accordingly, the ophthalmic measurement apparatus **1** of the embodiment can acquire the information of the posterior corneal surface Ec**2** without necessarily requiring an apparatus such as an anterior chamber OCT apparatus or a Scheimpflug camera which captures a cross-sectional image of the anterior chamber.

When the information of the posterior corneal surface is acquired from the cross-sectional image captured by an anterior chamber OCT apparatus, a Scheimpflug camera, or the like, an edge (boundary) of a cross section of the cornea in the image is detected. For example, the position of an edge of the posterior corneal surface in the image is specified as the position of the posterior corneal surface. However, typically, it is difficult to exactly specify the position of an edge of an object through image processing. The reason for this is that the position of detection of an edge of the same object changes depending on imaging conditions such as the amount of illumination light, even when an image of the same object is captured. In particular, it is considered that errors between an actual posterior corneal surface and the position of detection of an edge in a cross-sectional image of a subject eye occur depending on the optical characteristics (light transmittance of the cornea and the like) of the anterior chamber.

In contrast, the embodiment illustrates an example in which the posterior corneal surface is detected based on a distribution shape of a luminance distribution in each of the meridional directions in the image that contains the second Purkinje images. The distribution shape is dependent on the amount of illumination light, the optical characteristics of the anterior chamber, and the like, and the distribution shape is unlikely to be affected by the conditions such as the position of a peak value (maximum value) of the distribution and a median value of the curve containing a peak value. Accordingly, in the embodiment, the ophthalmic measurement apparatus **1** can acquire more exact information of the posterior corneal surface Ec**2** when acquiring the information of the posterior corneal surface from a cross-sectional image.

When the curvature of the posterior corneal surface is obtained, the curvature of the posterior corneal surface is preferably calculated using the corneal thickness of the subject eye E. Since a corneal pachymetry optical system is provided as the second measurement optical system, the use of another apparatus is not necessarily required. For example, the corneal pachymetry optical system has a configuration disclosed in JP-A-2012-143492.

Also in this case, the corneal pachymetry optical system preferably can measure a corneal thickness at one or more points of the cornea, and the provision of a complicated optical system such as a Scheimpflug camera with a rotating mechanism or an anterior chamber OCT necessitating a two-dimensional scanner is not necessarily required.

In the embodiment, a combined power of the cornea is obtained as the information of the posterior corneal surface Ec**2**. When a compounded power is obtained from a cross-sectional image, the ophthalmic measurement apparatus **1** obtains an exact compounded power. Accordingly, for example, the power obtained by the ophthalmic measurement apparatus **1** contributes to the selection of an appropriate power of an intraocular lens (IOL) for a subject eye.

It is difficult to cleanly form the second Purkinje images Rp**1** and Rp**2**. In contrast, in the embodiment, in the second Purkinje image capturing mode in which the second Purkinje images are detected and an image of the anterior chamber is acquired, the CPU **101** increases the amount of light from the light source **11** that projects the target light flux, or the gain of the photodetection element **27**, compared to at least the first Purkinje image capturing mode. As a result, it is easy to obtain image data containing clean second Purkinje images Rp**1** and Rp**2** in the second Purkinje image capturing mode. Accordingly, in the second Purkinje image detecting process (S**9**), good detection of the second Purkinje images Rp**1** and Rp**2** is easy.

The iris of the subject eye E is a region, in which the luminance changes complicatedly. For this reason, when the second Purkinje images Rp**1** and Rp**2** are formed so as to overlap with the iris, there is a problem in that it is difficult to detect the second Purkinje images Rp**1** and Rp**2**. In contrast, in the embodiment, in the second Purkinje image capturing mode, the CPU **101** reduces the amount of visible light which is applied to the subject eye E from the fixation target projection optical system **50**, compared to at least the first Purkinje image capturing mode. Accordingly, in the

second Purkinje image capturing mode, the contraction of the pupil resulting from glare is reduced. As a result, the second Purkinje images Rp**1** and Rp**2** are prevented from being formed at positions in which the second Purkinje images Rp**1** and Rp**2** overlap with the iris. Accordingly, with the ophthalmic measurement apparatus **1** of the embodiment, good detection of the second Purkinje images Rp**1** and Rp**2** is easy.

In the embodiment, vision fixation is performed so as to capture an anterior chamber image containing the second Purkinje images Rp**1** and Rp**2**, using the fixation target disposed at the far point of the subject eye E. Accordingly, it is possible to capture the anterior chamber image in a state where the pupil is less contracted. As a result, the second Purkinje images Rp**1** and Rp**2** are prevented from being formed at the positions in which the second Purkinje images Rp**1** and Rp**2** overlap with the iris, and with the ophthalmic measurement apparatus **1**, good detection of the second Purkinje images Rp**1** and Rp**2** is easy.

In the above description, the ophthalmic measurement apparatus **1** according to the embodiment is described, however, a configuration of the ophthalmic measurement apparatus **1** is not limited to those described in the above, and various modifications can be made thereto.

For example, typically, in addition to the first and second Purkinje images described in the embodiment, third and fourth Purkinje images are known as Purkinje images that are formed due to the light flux projected on the subject eye E being reflected from the anterior chamber. The third and fourth Purkinje images are respectively formed by the light flux reflected from the anterior lens surface and the posterior lens surface. Here, since the posterior lens surface reflects light less than the anterior lens surface does, when the second Purkinje images are detected from the anterior chamber image, the fourth Purkinje images are unlikely to become problematic. In contrast, the anterior lens surface reflects light more than the posterior lens surface does. As a result, third Purkinje images having the same level of brightness as that of the second Purkinje images may occur.

In contrast, for example, the keratoscopic projection optical system **10** (an example of a light projection optical system) may be configured so as to project a target pattern which is asymmetrical with respect to the meridian (center of an optical axis) of the cornea. In addition, the second Purkinje image capturing process (for example, the process in step S**9**) may be configured in such a manner that the second Purkinje images are detected from the upright reflected image of the target light flux. In an example of the configuration in which a target pattern is projected asymmetrically with respect to the meridian of the cornea, the ring light sources **11***a* and **11***b* may be partially (or intermittently) turned on. The ring light sources **11***a* and **11***b* may be replaced with a plurality of point light sources or the like which are disposed asymmetrically with respect to the meridian of the cornea.

FIG. **6** illustrates an anterior chamber image captured in a state where only a higher half portion of the light source **11** (here, the first ring light source **11***a*) is turned on, as an example. In the example illustrated in FIG. **6**, since the second Purkinje image is an upright reflected image, a second Purkinje image Rp is formed on the higher half portion of the cornea Ec. In contrast, a third Purkinje image Rq**1** is an inverted reflected image. For this reason, in the example illustrated in FIG. **6**, the third Purkinje image Rq**1** is formed on a lower half portion of the cornea Ec. At this time, for example, a range of detection of the second Purkinje image Rp in the image may be limited to a range (in this example, corneal portion or higher half portion of the image) of the formation of the upright reflected image so as to detect the second Purkinje image Rp from the upright reflected image. As a result, it is possible to reduce a probability of the CPU **101** erroneously detecting the third Purkinje image as the second Purkinje image.

Not only the keratoscopic projection optical system **10** but also the alignment projection optical system **30** may be used as projection optical system for target light flux that forms a Purkinje image. In the embodiment, when the alignment projection optical system **30** is also used as a projection optical system for the target light flux, an anterior chamber image may be captured by turning on light sources in turn, one at a time. An anterior chamber image may be captured by alternately turning on the light source **11***a* and the light source **31**, and the light source **11***b* in such a manner that two adjacent light sources (for example, the light source **11***a* and the light source **11***b*, and the light source **11***b* and the light source **31**) are not concurrently turned on. Accordingly, the Purkinje images (the first Purkinje image and the second Purkinje image) formed by the light sources are prevented from overlapping with Purkinje images formed by other light sources. As a result, the apparatus detects each of the Purkinje images well.

In the embodiment, the corneal thickness of the center corneal portion is used as a corneal thickness at the reference position of the cornea; however, the corneal thickness is not limited to the corneal thickness at the reference position of the cornea, and a corneal thickness in a region away from the center of the cornea may be used as the corneal thickness at the reference position.

In the embodiment, when the first Purkinje images Ra**1** and Ra**2** and the second Purkinje images Rp**1** and Rp**2** are captured, the anterior chamber illumination (for example, the light source **31**) may be turned off. That is, an image is preferably captured from which it is possible to detect position and shape information of each of the Purkinje images, and it is not necessary to capture an image from which it is possible to confirm each portion of the anterior chamber, for example, the position and shape of the pupil.

In the embodiment, the fixation target projection optical system **50** is described as an example of an auxiliary projection optical system that is controlled by the CPU **10** and projects illumination light on the subject eye E. However, the ophthalmic measurement apparatus **1** may be configured to be provided with, as the auxiliary projection optical system, one or more of other types of optical system that projects illumination light, which is different from the pattern target, on the subject eye E, in a case where the light has an influence on detection of the second Purkinje images Rp**1** and Rp**2**. The auxiliary projection optical system may include: the alignment projection optical system **30** configured to project an alignment target on the cornea of the subject eye E; an anterior chamber illumination optical system configured to project illumination light on the cornea of the subject eye E; and a measurement optical system configured to project measurement light on the subject eye for measuring optical characteristics of the subject eye E. In the embodiment, the alignment projection optical system **30** is configured to serve as the anterior chamber illumination optical system, and the second measurement optical system **40** serves as the measurement optical system.

In the embodiment, the second Purkinje images Rp**1** and Rp**2** are detected from single piece of image obtained by capturing an anterior chamber image. However, the detection of the second Purkinje images Rp**1** and Rp**2** is not necessarily limited to that in the embodiment. For example,

in the second Purkinje image capturing mode, a plurality of images, each of which having the same position of a pattern target, may be captured, and the CPU **101** may generate a sum image from these images. Thereafter, a process (for example, the process in step S**9**) of detecting the second Purkinje images Rp**1** and Rp**2** from the sum image may be performed. Since the sum image containing the clean second Purkinje images is obtained by summing the plurality of images, good detection of the second Purkinje images Rp**1** and Rp**2** is easy. The first Purkinje images Ra**1** and Ra**2** may be detected from a sum image. In a second Purkinje image capturing mode setting process (S**7**), the number of images summed is preferably set in such a manner that the number of images (the number of captured images) summed for detecting the second Purkinje images Rp**1** and Rp**2** is greater than that for detecting the first Purkinje images Ra**1** an Ra**2**.

In the embodiment, the respective imaging conditions of the first Purkinje image capturing mode and the second Purkinje image capturing mode are different from each other; however, the first Purkinje images and the second Purkinje images may be captured under the same conditions. For example, the first Purkinje images and the second Purkinje images may be detected from the same image.

In the embodiment, in the processes in steps S**6** and S**9**, the CPU **101** performs an image analysis process as an example of the Purkinje image detecting process; however, the present invention is not necessarily limited to that in the embodiment. For example, in at least one of the processes in steps S**6** and S**9**, the Purkinje images may be detected based on position information of the Purkinje images on the image which is input via the user interface **80** by the examiner who confirms the anterior chamber image displayed on the monitor **70** or the like.

In the embodiment, the information of the posterior corneal surface is acquired by the ophthalmic measurement apparatus **1**, but the present invention is not necessarily limited to that in the embodiment. For example, it is possible to obtain the information of the posterior corneal surface by transmitting the captured result (for example, image data) of the second Purkinje images to a general-purpose computer, and causing the computer to execute an analysis process. For example, when the information of the posterior corneal surface is acquired from the image data of the second Purkinje images and the image data of the first Purkinje images, an analysis program causing a processor of a computer to execute the processes in steps S**6**, S**9**, and S**10** illustrated in FIG. **3** may be provided in a hard disk of the computer or the like which stores a program for obtaining the information of the posterior corneal surface. Also in this case, the information of the posterior corneal surface is obtained similarly to the ophthalmic measurement apparatus **1** of the embodiment.

What is claimed is:

1. An ophthalmic measurement apparatus comprising:

a projection optical system configured to project a pattern target toward a cornea of a subject eye;

an imaging optical system provided with an imaging device configured to capture an image of the subject eye, the image including a second Purkinje image, which is a target image formed due to the pattern target being reflected from a posterior corneal surface of the subject eye;

a processor connected to the imaging device; and

a memory storing computer readable instructions, when executed by the processor, causing the processor to function as:

a detecting unit configured to detect the second Purkinje image from the image captured by the imaging device;

an acquiring unit configured to acquire posterior corneal surface information related to the posterior corneal surface of the subject eye based on the second Purkinje image detected by the detecting unit;

wherein the projection optical system is configured to selectively project one of a plurality of pattern targets on cornea to have an asymmetric shape with respect to a center of the cornea;

the processor controls the projection optical system to selectively project one of the pattern targets before performing detection of the second Purkinje image; and

the processor detects the second Purkinje image from an upright reflected image of the selectively projected asymmetric pattern target.

2. The ophthalmic measurement apparatus according to claim **1**,

wherein the imaging device captures the image of the subject eye further including a first Purkinje image, which is a target image formed due to the pattern target being reflected from an anterior corneal surface of the subject eye,

wherein the detecting unit is configured to detect the first Purkinje image from the image captured by the imaging device, and

wherein the acquiring unit is configured to acquire anterior corneal surface information related to the anterior corneal surface of the subject eye based on the first Purkinje image detected by the detecting unit.

3. The ophthalmic measurement apparatus according to claim **2**,

wherein the acquiring unit is configured to acquire the posterior corneal surface information based on the first Purkinje image and the second Purkinje image detected by the detecting unit.

4. The ophthalmic measurement apparatus according to claim **2**,

wherein the acquiring unit is configured to acquire the posterior corneal surface information based on the second Purkinje image detected by the detecting unit, the anterior corneal surface information acquired by the acquiring unit, and corneal thickness information related to corneal thickness of the subject eye at a reference position.

5. The ophthalmic measurement apparatus according to claim **4** further comprising:

a corneal pachymetry optical system configured to measure the corneal thickness of the subject eye at the reference position.

6. The ophthalmic measurement apparatus according to claim **5**,

wherein the acquiring unit is configured to acquire a corneal thickness distribution of the subject eye as the posterior corneal surface information based on:

curvature information of the posterior corneal surface of the subject eye obtained from the second Purkinje image;

curvature information of the anterior corneal surface of the subject eye obtained from the first Purkinje image; and

the corneal thickness of the subject eye at the reference position.

7. The ophthalmic measurement apparatus according to claim **2**,

wherein the acquiring unit is configured to acquire a power of the cornea by applying vector synthesis on a power of the anterior corneal surface and a power of the posterior corneal surface.

8. The ophthalmic measurement apparatus according to claim **1**,

wherein the acquiring unit is configured to acquire a curvature radius of the posterior corneal surface as the posterior corneal surface information.

9. The ophthalmic measurement apparatus according to claim **1**,

wherein the memory further stores computer readable instructions, when executed by the processor, causing the processor to function as:

a mode setting unit configured to set an operational mode into one of: a first Purkinje image capturing mode in which the imaging optical system is set to capture the image of the subject eye for detecting the first Purkinje image; and a second Purkinje image capturing mode in which the imaging optical system is set to capture the image of the subject eye for detecting the second Purkinje image; and

an imaging control unit configured to change imaging condition of the image captured by the imaging device in the imaging optical system in accordance with the operational mode being set by the mode setting unit.

10. The ophthalmic measurement apparatus according to claim **9**,

wherein the imaging control unit is configured to set at least one of an amount of projection light of the pattern target projected by the projection optical system and a gain of the imaging device in the second Purkinje image capturing mode to be larger than in the first Purkinje image capturing mode.

11. The ophthalmic measurement apparatus according to claim **9** further comprising:

an auxiliary projection optical system configured to project light that is different from the pattern target toward a cornea of a subject eye,

wherein the imaging control unit is configured to control the auxiliary projection optical system to reduce amount of the light when the second Purkinje image capturing mode is set by the mode setting unit than in the first Purkinje image capturing mode.

12. The ophthalmic measurement apparatus according to claim **11**,

wherein the auxiliary projection optical system comprises at least one of:

a fixation target projection optical system configured to project a fixation target on the subject eye;

an alignment projection optical system configured to project an alignment target on the cornea of the subject eye;

an anterior chamber illumination optical system configured to project illumination light on the cornea of the subject eye; and

a measurement optical system configured to project measurement light on the subject eye for measuring optical characteristics of the subject eye.

13. The ophthalmic measurement apparatus according to claim **11**,

wherein the light projected from the auxiliary projection optical system contains light which is to be reflected from the fundus and applied to the cornea.

14. The ophthalmic measurement apparatus according to claim **11**,

wherein the auxiliary projection optical system is configured to project a fixation target on the subject eye, the fixation target being emitted from a visible light source.

15. The ophthalmic measurement apparatus according to claim **9** further comprising:

a fixation target position adjusting mechanism configured to adjust a position of a fixation target projected to the subject eye,

wherein the memory further stores computer readable instructions, when executed by the processor, causing the processor to function as:

a fixation target position control unit configured to control the fixation target position adjusting mechanism to set the position of the fixation target to be at a far point of the subject eye when the imaging device captures the image for detecting the second Purkinje image at least when the operational mode is set to the second Purkinje image capturing mode.

16. The ophthalmic measurement apparatus according to claim **1**,

wherein the projection optical system is configured to project a plurality of concentric ring target patterns as the pattern targets,

wherein the detecting unit is configured to detect the second Purkinje image for each of the ring target patterns, and

wherein the acquisition unit is configured to acquire posterior corneal surface information for posterior corneal surface regions different in a meridional direction of the cornea.

17. The ophthalmic measurement apparatus according to claim **16**,

wherein the memory further stores computer readable instructions, when executed by the processor, causing the processor to function as:

a projection control unit configured to control the projection optical system to selectively project at least one of the plurality of ring target patterns.

18. A method for measuring cornea of a subject eye, the method comprising:

projecting a pattern target toward a cornea of a subject eye;

capturing an image of the subject eye, the image including a second Purkinje image, which is a target image formed due to the pattern target being reflected from a posterior corneal surface of the subject eye;

detecting the second Purkinje image from the image of the subject eye; and

acquiring posterior corneal surface information related to the posterior corneal surface of the subject eye based on the second Purkinje image detected from the image from the image of the subject eye;

wherein the projecting step includes selectively projecting one of a plurality of pattern targets on cornea to have asymmetric shape with respect to a center of the cornea before detecting the second Purkinje image; and

the detecting step includes detecting the second Purkinje image from an upright reflected image of the selectively projected asymmetric pattern target.

19. The ophthalmic measurement apparatus according to claim **1**, wherein the second Purkinje image is detected from a summed image created by summing up a plurality of images captured for a same position of the pattern target.

20. The ophthalmic measurement apparatus according to claim **1**, wherein the projection optical system is provided with a plurality of light sources including a ring light source and a point light source that includes a plurality of point light

source elements arranged to have a ring shape, the plurality of light sources being controlled to be selectively turned on to create the plurality of pattern targets.

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